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FORM PTO-1390 (REV 11-98) U.S. DEPARTMENT OF COMMERCE PATENT AND TRADEMARK OFFICE

ATTORNEY'S DOCKET NUMBER: 6550-000017/US1

TRANSMITTAL LETTER TO THE UNITED STATES DESIGNATED/ELECTED OFFICE (DO/EO/US) CONCERNING A FILING UNDER 35 U.S.C. 371

U.S. APPLICATION NO. (If known, see 37 CFR 1.5): 09/601540

INTERNATIONAL APPLICATION NO	INTERNATIONAL FILING DATE	PRIORITY DATE CLAIMED
PCT/US99/02897	February 11, 1999	February 12, 1998

TITLE OF INVENTION: Micro-Fastening System and Method of Manufacture

APPLICANT(S) FOR DO/EO/US: David Tomanek; Richard Enbody; Young-Kyun Kwon

Applicant herewith submits to the United States Designated/Elected Office (DO/EO/US) the following items and other information:

1. [X] This is a **FIRST** submission of items concerning a filing under 35 U.S.C. 371.
2. [ ] This is a **SECOND or SUBSEQUENT** submission of items concerning a filing under 35 U.S.C. 371.
3. [X] This express request to begin national examination procedures (35 U.S.C. 371(f)) at any time rather than delay examination until the expiration of the applicable time limit set in 35 U.S.C. 371(b) and PCT Articles 22 and 39(1).
4. [ ] A proper Demand for International Preliminary Examination was made by the 19th month from the earliest claimed priority date.
5. [X] A copy of the International Application as filed (35 U.S.C. 371(c)(2))
   a. [X] is transmitted herewith (required only if not transmitted by the International Bureau).
   b. [ ] has been transmitted by the International Bureau.
   c. [ ] is not required, as the application was filed in the United States Receiving Office (RO/US).
6. [ ] A translation of the International Application into English (35 U.S.C. 371(c)(2)).
7. [X] Amendments to the claims of the International Application under PCT Article 19 (35 U.S.C. 371(c)(3))
   a. [ ] are transmitted herewith (required only if not transmitted by the International Bureau).
   b. [ ] have been transmitted by the International Bureau.
   c. [ ] have not been made; however, the time limit for making such amendments has NOT expired.
   d [X] have not been made and will not be made.
8. [ ] A translation of the amendments to the claims under PCT Article 19 (35 U.S.C. 371(c)(3)).
9. [ ] An oath or declaration of the inventor(s) (35 U.S.C. 371(c)(4)).
10. [ ] A translation of the annexes to the International Preliminary Examination Report under PCT Article 36 (35 U.S.C. 371(c)(5)).

Items 11. to 16. below concern document(s) or information included:

11. [ ] An Information Disclosure Statement under 37 CFR 1.97 and 1.98.
12. [ ] An assignment document for recording. A separate cover sheet in compliance with 37 CFR 3.28 and 3.31 is included.
13. [ ] A FIRST preliminary amendment.
    [ ] A SECOND or SUBSEQUENT preliminary amendment.
14. [ ] A substitute specification.
15. [ ] A change of power of attorney and/or address letter.
16. [X] Other items or information: return postcard; 2 sheets of drawings showing Figures 1-4 and copy of Reply to Written Opinion and Article 34 Amendment

U.S. APPLICATION NO. (if known, see 37 CFR 1.5)	INTERNATIONAL APPLICATION NO.	ATTORNEY'S DOCKET NUMBER
09/601540	PCT/US99/02897	6550-000017/US1

17. ☐ The following fees are submitted:	CALCULATIONS	PTO USE ONLY
BASIC NATIONAL FEE (37 CFR 1.492 (a) (1) - (5)):		
Neither international preliminary examination fee (37 CFR 1.482) nor international search fee (37 CFR 1.445(a)(2)) paid to USPTO and International Search Report not prepared by the EPO or JPO $970.00		
International preliminary examination fee (37 CFR 1.482) not paid to USPTO but International Search Report prepared by the EPO or JPO..... $840.00		
International preliminary examination fee (37 CFR 1.482) not paid to USPTO but international search fee (37 CFR 1.445(a)(2)) paid to USPTO $760.00		
International preliminary examination fee paid to USPTO (37 CFR 1.482) but all claims did not satisfy provisions of PCT Article 33(1)-(4)..... $670.00		
International preliminary examination fee paid to USPTO (37 CFR 1.482) and all claims satisfied provisions of PCT Article 33(1)-(4) $96.00		
ENTER APPROPRIATE BASIC FEE AMOUNT =	$670.00	
Surcharge of $130.00 for furnishing the oath or declaration later than ☐ 20 ☐ 30 months from the earliest claimed priority date (37 CFR 1.492(e)).	$-0-	

CLAIMS	NUMBER FILED	NUMBER EXTRA	RATE		
Total claims	- 20 =		X $18.00	$-0-	
Independent claims	- 3 =		X $78.00	$-0-	
MULTIPLE DEPENDENT CLAIM(S) (if applicable)			+ $260.00		
TOTAL OF ABOVE CALCULATIONS =				$670.00	
Reduction of 1/2 for filing by small entity, if applicable. A Small Entity Statement must also by filed (Note 37 CFR 1.9, 1.27, 1.28).				$ -0-	
SUBTOTAL =				$670.00	
Processing fee of $130.00 for furnishing the English translation later than ☐20 ☐30 months from the earliest claimed priority date (37 CFR 1.492(f)). +				$-0-	
TOTAL NATIONAL FEE =				$670.00	
Fee for recording the enclosed assignment (37 CFR 1.21(h)). The assignment must be accompanied by an appropriate cover sheet (37 CFR 3.28, 3.31). $40.00 per property +				$-0-	
TOTAL FEES ENCLOSED =				$670.00	
				Amount to be: refunded	$
				charged	$

a. ☒ A check in the amount of $670.00 to cover the above fees is enclosed

b. ☐ Please charge my Deposit Account No. _____ in the amount of $_____ to cover the above fees. A duplicate copy of this sheet is enclosed.

c. ☒ The Commissioner is hereby authorized to charge any additional fees which may be required, or credit any overpayment to Deposit Account No. 18-0750. A duplicate copy of this sheet is enclosed.

NOTE: Where an appropriate time limit under 37 CFR 1.494 or 1.495 has not been met, a petition to revive (37 CFR 1.137(a) or (b)) must be filed and granted to restore the application to pending status.

SEND ALL CORRESPONDENCE TO:

Robert M. Siminski
Harness, Dickey & Pierce, P.L.C.
P.O. Box 828
Bloomfield Hills, MI 48303

Robert M Siminski

SIGNATURE:
Robert M. Siminski

NAME
36,007

REGISTRATION NUMBER

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Date: August 1, 2000

Hon. Commissioner of Patents
and Trademarks
Washington, D.C. 20231

Sir:

EXPRESS MAILING CERTIFICATE

Applicant:	David Tomanek et al.
Serial No. (if any):	not yet assigned
For:	MICRO-FASTENING SYSTEM AND METHOD OF MANUFACTURE
Docket:	6550-000017/US1
Attorney:	Robert M. Siminski

"Express Mail" Mailing Label Number ..... EL 486 617 544 US

Date of Deposit ..... August 1, 2000

I hereby certify and verify that the accompanying return postcard; check in the amount of $670; Transmittal Letter; 11 page patent application; 2 sheets of drawings showing Figs. 1-4b; unsigned Declaration and Power of Attorney; copy of Reply to Written Opinion and Article 34 Amendment and this Express Mailing Certificate are being deposited with the United States Postal Service "Express Mail Post Office To Addressee" service under 37 C.F.R. 1.10 on the date indicated above and are addressed to the Commissioner of Patents and Trademarks, Washington, D.C. 20231.

Carol Darnielle

Carol Darnielle

IN THE UNITED STATES PATENT AND TRADEMARK OFFICE

Inventor(s) or Patentee: David Tomanek et al.
Serial or Patent No.:
Filed or Issued:
For: Micro-Fastening System and Method of Manufacture

Attorney Docket No.: 6550-000017/US1

VERIFIED STATEMENT (DECLARATION) CLAIMING SMALL ENTITY STATUS (37 CFR 1.9(f) and 1.27(d)) - NONPROFIT ORGANIZATION

I hereby declare that I am an official empowered to act on behalf of the nonprofit organization identified below:

NAME OF ORGANIZATION: Board of Trustees Operating Michigan State University

ADDRESS OF ORGANIZATION: East Lansing, Michigan 48824

TYPE OF ORGANIZATION:

[X] University or other institution of higher education
[ ] Tax exempt under Internal Revenue Service Code (26 USC 501(a) and 501(c)(3))
[ ] Nonprofit scientific or educational under statute of state of The United States of America

(Name of state: _____)

(Citation of statute: _____)

[ ] Would qualify as tax exempt under Internal Revenue Service Code (26 USC 501(a) and 501(c)(3)) if located in The United States of America
[ ] Would qualify as nonprofit scientific or educational under statute of state of The United States of America if located in The United States of America

(Name of state: _____)

(Citation of statute: _____)

I hereby declare that the nonprofit organization identified above qualifies as a nonprofit organization as defined in 37 CFR 1.9(e) for purposes of paying reduced fees under section 41(a) and (b) of Title 35, United States Code with regard to the invention entitled

Micro-Fastening System and Method of Manufacture

by inventor(s) David Tomanek et al.

described in

[ ] the specification filed herewith
[X] application serial no. _____ filed _____
[ ] patent no. _____ issued _____

VERIFIED STATEMENT (DECLARATION) CLAIMING SMALL ENTITY STATUS (37 CFR 1.9(f) AND 1.27(d)) - NONPROFIT ORGANIZATION

I hereby declare that rights under contract or law have been conveyed to and remain with the nonprofit organization with regard to the above-identified invention.

If the rights held by the nonprofit organization are not exclusive, each individual, concern or organization having rights to the invention is listed below* and no rights to the invention are held by any person, other than the inventor, who could not qualify as an independent inventor under 37 CFR 1.9(c) if that person had made the invention, or by any concern which would not qualify as a small business concern under 37 CFR 1.9(d) or a nonprofit organization under 37 CFR 1.9(e).

*NOTE: Separate verified statements are required from each named person, concern or organization having rights to the invention averring to their status as small entities. (37 CFR 1.27)

NAME: _____

ADDRESS: _____

_____

[ ] Individual [ ] Small Business Concern [ ] Nonprofit Organization

NAME: _____

ADDRESS: _____

_____

[ ] Individual [ ] Small Business Concern [ ] Nonprofit Organization

I acknowledge the duty to file, in this application or patent, notification of any change in status resulting in loss of entitlement to small entity status prior to paying, or at the time of paying, the earliest of the issue fee or any maintenance fee due after the date on which status as a small entity is no longer appropriate. (37 CFR 1.28(b))

I hereby declare that all statements made herein of my own knowledge are true and that all statements made on information and belief are believed to be true; and further that these statements were made with the knowledge that willful false statements and the like so made are punishable by fine or imprisonment, or both, under section 1001 of Title 18 of the United States Code, and that such willful false statements may jeopardize the validity of the application, any patent issuing thereon, or any patent to which this verified statement is directed.

Name of Person Signing: Norman M. Pollack, Ph.D.

Title in Organization: Assistant Vice President for Intellectual Property

Address of Person Signing: Michigan State University, East Lansing, Michigan 48824

Signature: _____ Date: 8/4/00

Attorney Docket No. 6550-000017/POA

IN THE UNITED STATES PATENT AND TRADEMARK OFFICE

Applicant:	Board of Trustees Operating Michigan State University et al.	
International Filing Date:	(11.02.99) 11 February 1999	**REPLY TO WRITTEN OPINION AND ARTICLE 34 AMENDMENT**
International Application No:	PCT/US99/02897	
For:	MICRO-FASTENING SYSTEM AND METHOD OF MANUFACTURE	

Hon. Commissioner of Patents
and Trademarks
Box PCT
Washington, D.C. 20231

In the Claims

Please amend the claims as follows:

1. (Amended) A microfastening system comprising:

a first fastening element including a plurality of extending nanotubes; and

a second fastening element including a plurality of extending nanotubes;

whereby upon joining said first and second fastening elements, the extending nanotubes from each element become mechanically interconnected without requiring the degradation of said nanotubes.

9. (Amended) A microfastener comprising:

a substrate including an attachment surface; and

a plurality of functionalized non-linear nanotubes attached to and extending from said attachment surface, whereby said microfastener can be joined to another element including extending nanotubes without requiring the degradation of said nanotubes.

14. (Amended) A method of manufacturing a microfastener comprising the steps of:

a) providing a substrate having an attachment surface;

b) introducing a plurality of open ended nanotubes to said substrate whereby said nanotubes are attracted to said attachment surface and become affixed thereto, whereby said microfastener can be joined to another element including extending nanotubes without requiring the degradation of said nanotubes.

Please add Claims 24-43 as follows:

24. (New) A microfastening system comprising:

a first fastening element including a plurality of extending nanotubes; and

a second fastening element including a plurality of extending nanotubes, wherein said nanotubes of at least one of said fastening elements are selectively deformable;

whereby upon joining said first and second fastening elements, the extending nanotubes from each element become mechanically interconnected.

25. (New) The microfastening system of Claim 24 wherein said at least one of first and second fastening elements further comprise a substrate from which said nanotubes extend.

26. (New) The microfastening system of Claim 25 wherein said substrate is formed from materials selected from the group consisting of metals, carbon, silicon, germanium, polymers and composites thereof.

27. (New) The microfastening system of Claim 24 wherein said nanotubes are at least partially multi-walled.

28. (New) The microfastening system of Claim 24 wherein the nanotubes are functionalized to a non-linear shape.

29. (New) The microfastening system of Claim 28 wherein the non-linear nanotubes of said fastening element are selected from hooks, loops, spirals and combinations thereof.

30. (New) The microfastening system of Claim 24 wherein said fastening elements are reusable.

31. (New) A microfastener comprising:

a substrate including an attachment surface; and

a plurality of functionalized selectively deformable non-linear nanotubes attached to and extending from said attachment surface.

32. (New) The microfastener of Claim 31 wherein said substrate is formed from materials selected from the group consisting of metals, carbon, silicon, germanium, polymers and composites thereof.

33. (New) The microfastener of Claim 31 wherein said nanotubes are at least partially multi-walled.

34. (New) The microfastener of Claim 31 wherein the non-linear nanotubes of said fastening element are selected from hooks, loops, spirals and combinations thereof.

35. (New) A method of manufacturing a microfastener comprising the steps of:

a) providing a substrate having an attachment surface;

b) introducing a plurality of open ended selectively deformable non-linear nanotubes to said substrate whereby said nanotubes are attracted to said attachment surface and become affixed thereto.

36. (New) The method of Claim 35 wherein said nanotubes are functionalized prior to attaching to said substrate.

37. (New) The method of Claim 35 wherein said nanotubes are functionalized during attachment to said substrate.

38. (New) The method of Claim 35 wherein said nanotubes are functionalized after attachment to said substrate.

39. (New) The method of Claim 35 wherein said substrate is formed from materials selected from the group consisting of metals, carbon, silicon, germanium, polymers and composites thereof.

40. (New) The method of Claim 35 wherein said nanotubes are at least partially multi-walled.

41. (New) The method of Claim 35 wherein the non-linear nanotubes of said microfastener are selected from hooks, loops, spirals and combinations thereof.

42. (New) The method of Claim 35 wherein said nanotubes are attached to said substrate in the presence of an electric field.

43. (New) The method of Claim 35 wherein said microfastener is reusable.

REMARKS

Upon review of the Written Opinion dated 12 January 2000, the Authorized Officer has indicated that Claims 1-6, 9-12, 14, 15, and 18-20 lack novelty under PCT Article 33(2) as being anticipated by U.S. Patent No. 5,464,987 to Ihara et al. The Authorized Officer states that Ihara et al. discloses a first fastening element in Fig. 10 including a plurality of extending nanotubes and a second fastening element including a plurality of extending nanotubes whereby the extending nanotubes of each fastening element are mechanically interconnected.

While the Applicants respectfully disagree with the Authorized Officer's interpretation of Ihara et al., Applicants have amended independent claims 1, 9 and 14 in an effort to more clearly define the scope of the invention.

As is clear from a review of Fig. 10 in Ihara et al., the interconnected chain of nanotubes depicted in Ihara et al. requires degradation and reformation of the nanotube chain links in order to arguably accomplish a "fastening element". This degradation involves a destruction of the atomic bonds forming the nanotube to provide sufficient clearance to accomplish a link between the consecutive nanotube chain elements of Ihara et al. In contrast, the fastening elements of the present invention can be connected and disconnected without requiring the above described degradation.

Regarding new Claims 24-43, Applicants have considered the Authorized Officer's notation that Ihara et al. fails to teach an interengaging fastening system wherein at least one of the interconnected or adjoined fastening elements is

selectively deformable. As such, language reflecting this limitation has been included in independent claims 24, 31 and 35 respectively.

Thus, since the claims as currently pending demonstrate both novelty and the requisite inventive steps, Applicant respectfully submits that each of the pending claims should be in a condition for allowance. Upon review of the foregoing, if the Authorized Officer has any questions, he is encouraged to contact the undersigned at his earliest convenience.

Lastly, please note that substitute pages 8-15 have been included herewith for entry into the application.

Respectfully submitted,

By: Robert M Siminski
Robert M. Siminski
Reg. No. 36,007

HARNESS, DICKEY & PIERCE, P.L.C.
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Date: March 10 2000

RMS/csd

CLAIMS

1. A microfastening system comprising:

a first fastening element including a plurality of extending nanotubes; and

a second fastening element including a plurality of extending nanotubes, wherein said nanotubes of at least one of said fastening elements are selectively deformable;

whereby upon joining said first and second fastening elements, the extending nanotubes from each element become mechanically interconnected without requiring the degradation of said nanotubes.

2. The microfastening system of Claim 1 wherein said at least one of first and second fastening elements further comprise a substrate from which said nanotubes extend.

3. The microfastening system of Claim 2 wherein said substrate is formed from materials selected from the group consisting of metals, carbon, silicon, germanium, polymers and composites thereof.

4. The microfastening system of Claim 1 wherein said nanotubes are at least partially multi-walled.

5. The microfastening system of Claim 1 wherein the nanotubes are functionalized to a non-linear shape.

6. The microfastening system of Claim 5 wherein the non-linear nanotubes of said fastening element are selected from hooks, loops, spirals and combinations thereof.

7. The microfastening system of Claim 1 wherein said nanotubes of at least one of said fastening elements are selectively deformable.

8. The microfastening system of Claim 1 wherein said fastening elements are reusable.

9. A microfastener comprising:

a substrate including an attachment surface; and

a plurality of functionalized selectively deformable non-linear nanotubes attached to and extending from said attachment surface.

10. The microfastener of Claim 9 wherein said substrate is formed from materials selected from the group consisting of metals, carbon, silicon, germanium, polymers and composites thereof.

11. The microfastener of Claim 9 wherein said nanotubes are at least partially multi-walled.

12. The microfastener of Claim 9 wherein the non-linear nanotubes of said fastening element are selected from hooks, loops, spirals and combinations thereof.

13. The microfastener of Claim 9 wherein at least some of the nanotubes of said microfastener are selectively deformable.

14. A method of manufacturing a microfastener comprising the steps of:

a) providing a substrate having an attachment surface;

b) introducing a plurality of open ended selectively deformable nanotubes to said substrate whereby said nanotubes are attracted to said attachment surface and become affixed thereto.

15. The method of Claim 14 wherein said nanotubes are functionalized prior to attaching to said substrate.

16. The method of Claim 14 wherein said nanotubes are functionalized during attachment to said substrate.

17. The method of Claim 14 wherein said nanotubes are functionalized after attachment to said substrate.

18. The method of Claim 14 wherein said substrate is formed from materials selected from the group consisting of metals, carbon, silicon, germanium, polymers and composites thereof.

19. The method of Claim 14 wherein said nanotubes are at least partially multi-walled.

20. The method of Claim 14 wherein the non-linear nanotubes of said fastening element are selected from hooks, loops, spirals and combinations thereof.

21. The method of Claim 14 wherein at least some of said nanotubes are selectively deformable.

22. The method of Claim 14 wherein said nanotubes are attached to said substrate in the presence of an electric field.

23. The method of Claim 14 wherein said microfastener is reusable.

24. A microfastening system comprising:

a first fastening element including a plurality of extending nanotubes; and

a second fastening element including a plurality of extending nanotubes, wherein said nanotubes of at least one of said fastening elements are selectively deformable;

whereby upon joining said first and second fastening elements, the extending nanotubes from each element become mechanically interconnected.

25. The microfastening system of Claim 24 wherein said at least one of first and second fastening elements further comprise a substrate from which said nanotubes extend.

26. The microfastening system of Claim 25 wherein said substrate is formed from materials selected from the group consisting of metals, carbon, silicon, germanium, polymers and composites thereof.

27. The microfastening system of Claim 24 wherein said nanotubes are at least partially multi-walled.

28. The microfastening system of Claim 24 wherein the nanotubes are functionalized to a non-linear shape.

29. The microfastening system of Claim 28 wherein the non-linear nanotubes of said fastening element are selected from hooks, loops, spirals and combinations thereof.

30. The microfastening system of Claim 24 wherein said fastening elements are reusable.

31. A microfastener comprising:

a substrate including an attachment surface; and

a plurality of functionalized selectively deformable non-linear nanotubes attached to and extending from said attachment surface.

32. The microfastener of Claim 31 wherein said substrate is formed from materials selected from the group consisting of metals, carbon, silicon, germanium, polymers and composites thereof.

33. The microfastener of Claim 31 wherein said nanotubes are at least partially multi-walled.

34. The microfastener of Claim 31 wherein the non-linear nanotubes of said fastening element are selected from hooks, loops, spirals and combinations thereof.

35. A method of manufacturing a microfastener comprising the steps of:

a) providing a substrate having an attachment surface;

b) introducing a plurality of open ended selectively deformable non-linear nanotubes to said substrate whereby said nanotubes are attracted to said attachment surface and become affixed thereto.

36. The method of Claim 35 wherein said nanotubes are functionalized prior to attaching to said substrate.

37. The method of Claim 35 wherein said nanotubes are functionalized during attachment to said substrate.

38. The method of Claim 35 wherein said nanotubes are functionalized after attachment to said substrate.

39. The method of Claim 35 wherein said substrate is formed from materials selected from the group consisting of metals, carbon, silicon, germanium, polymers and composites thereof.

40. The method of Claim 35 wherein said nanotubes are at least partially multi-walled.

41. The method of Claim 35 wherein the non-linear nanotubes of said microfastener are selected from hooks, loops, spirals and combinations thereof.

42. The method of Claim 35 wherein said nanotubes are attached to said substrate in the presence of an electric field.

43. The method of Claim 35 wherein said microfastener is reusable.

ABSTRACT OF THE DISCLOSURE

The present invention relates to a micro-fastening system and, more particularly, to a mechanical micro-fastening system employing a plurality of mating nanoscale fastening elements (16, 18) and a method of manufacturing a micro-fastening system in accordance with the teachings of the present invention. The mating nanoscale fastening elements (16, 18) are formed by functionalizing nanotubes having an ordered array of hexagons with pentagons and heptagons at particular heterojunctions.

2/PRTS

TITLE

MICRO-FASTENING SYSTEM AND METHOD OF MANUFACTURE

BACKGROUND OF THE INVENTION

1. Field of the Invention

The present invention relates to a micro-fastening system and, more particularly, to a mechanical micro-fastening system employing a plurality of mating nanoscale fastening elements and a method of manufacturing the same.

2. Description of the Prior Art

Micro-fastening systems per se are utilized to connect distinct components brought into relative contact by strong bonds which span a gap at the interface and generally are less than one micrometer in size. In their most common embodiments, such microfastening systems have generally been in the form of chemical bonds such as adhesive bonds, welds and coatings. Numerous potential disadvantages associated with employing adhesives and coatings are known such as the irreversible nature of the bonds and the potential for degradation at relatively high temperatures. Further, adhesives and coatings generally require smooth dry interfaces which are free of impurities to effectuate high quality bonds. Welding results in a physical deformation of the surfaces being welded; it cannot be used effectively for interconnecting microscopically small components or large interface areas. Thus, there is a need for the mechanical "micro-fastening" system of the present invention.

SUMMARY OF THE INVENTION

The micro-fastening system of the present invention employs a plurality of mating nanoscale fastening elements which are obtained by structurally modifying, i.e., functionalizing nanotubes generally and carbon nanotubes particularly. Carbon nanotubes per se consist of a graphite monolayer having the overall shape of a cylinder including an ordered array of hexagonal carbon rings disposed along the cylindrical side walls which may be single or

multi-walled as reported in *Nature*, Vol. 354 (1991) pp. 56 - 58 and ibid. Vol. 363 (1993) pp. 603 - 605. The ends of the tubes are often closed by pairs of pentagonal carbon rings. Carbon nanotubes generally range in diameter from one to about 50 nanometers, and may be as long as approximately 0.1 millimeters. While related to carbon fibers, nanotubes are free of atomic scale defects, which accounts for their high tensile strength, as compared to that of the strength of individual graphite layers. Like graphite, carbon nanotubes exhibit sp^2 bonding which gives rise to a relatively high degree of flexibility and resilience. Further, carbon nanotubes are structurally stable nearly up to the melting point of graphite, i.e., up to about 3,500 degrees Celsius.

By functionalizing the carbon nanotubes as will be described in greater detail below, the cylindrical shape can be modified to include bent portions. While it has been suggested generally that carbon nanotubes can be readily functionalized, it has yet to be reported that carbon nanotubes can be specifically functionalized so as to obtain mating fastening elements as herein described.

Among the various applications for the micro-fastening system of the present invention are the assembly of nano-robots useful for micro-surgical procedures, surface coatings, and attachment of metal contacts to integrated semiconductor devices, by way of non-limiting example.

The strength of micro-fastening systems described herein relies on the enormous stability of nanotubes, i.e., their large structural rigidity, the high strength of the bonds anchoring tubes in a substrate and a large number of connections possible on a limited surface area. In contrast to purely mechanical fasteners (such as bolts and screws) which weaken the surfaces to be connected, there is no apparent degradation of the opposing surfaces to be joined under the present invention. Adhesives are typically weaker than most mechanical fasteners and their strength is strongly diminished at higher temperatures. Welding is not practicable for large interfaces, whereas the fastening system of the present invention may be employed for both large and microscopically small interfaces. Bonding technologies excepting the

micro-fastening system of the present invention leave macroscopically large gaps at the interface. Unlike known bonds between substrates, the micro-fastening system of the present invention has an effective thickness of the gap at interface as small as a few nanometers.

A further advantage of the present invention is that the surface bonds based on the nanotube based micro-fastening system, while extremely strong, may be re-opened and re-closed, i.e., they are reusable, whereas the surface bonds generated by gluing or welding are permanent. Thus, the micro-fastening system of the present invention is selectively reversible which is considered to be highly desirable, particularly for self-repair. This reusability or self-repairability is of particular advantage for interconnects exposed to changing forces or changing environmental variables (such as temperature) that result in a different expansion of the individual components brought into relative contact.

Still another advantage offered by the micro-fastening system of the present invention is that the conductivity of the fastening elements connecting the corresponding substrates may be varied from metallic to insulating, depending largely on the chemical composition, the diameter and chirality of the nanotubes.

BRIEF DESCRIPTION OF THE DRAWINGS

Figures 1(a-c) are a series of views demonstrating the representative closure mechanism and forces for a generic micro-fastening system in accordance with the teachings of the present invention.

Figures 1(d-f) are a series of views demonstrating the representative opening mechanism and forces for a micro-fastening system in accordance with the teachings of the present invention.

Figure 2 is a schematic view illustrating a way to define the figure of merit of the micro-fastening system wherein the horizontal axis X represents the separation between the surfaces.

Figures 3(a-d) are a series of views demonstrating the representative opening and closure mechanisms and forces for a particular micro-fastening

system based on nanotubes functionalized to form a mating hook and loop arrangement in accordance with the teachings of the present invention.

Figures 4(a-b) are illustrative of alternative mating nanoscale micro-fastening system elements in accordance with the teachings of the present invention.

DETAILED DESCRIPTION OF THE INVENTION

The micro-fastening system 10 of the present invention comprises a plurality of mating nanoscale fastening elements 12 and 12' manufactured by modifying, i.e., functionalizing nanotubes which are generally linear in nature prior to functionalizing. Upon functionalizing the nanotubes 14, fastening elements are obtained in a variety of non-linear forms such as hooks 16 and loops 18 as illustrated in Figs. 3(a-d) and spirals 20 as illustrated in Fig. 4(b) by way of non-limiting example. The nanotubes employed may be composed of carbon, nitrogen, boron or other elements which give rise to layered honeycomb lattice structures. It is important from the outset to note that the nanotubes employed in accordance with the teachings of the present invention may be single walled, multi-walled or at least partially multi-walled over the length of the nanotube. For simplicity, the present invention will hereinafter generally be described in terms of functionalizing graphitic carbon nanotubes.

By "functionalizing" graphitic carbon nanotubes, it is meant that a specific number of pentagons and heptagons are substituted for hexagons within the nanotube or are added along the open edge(s) of the core nanotube which consists of an ordered array of hexagons.

Upon introducing pentagons and heptagons in a predetermined order, the carbon nanotubes will exhibit a locally positive or negative Gaussian curvature that results in a "bend" in the nanotube. By continuing to add pentagons and hexagons in a specific manner, the bend of the nanotube can be grown until the desired shape is obtained.

Upon growing the carbon nanotube to the desired length and shape, a first end 22 of the nanotube 14 may be capped or terminated, e.g., by

introducing or forming a fullerene half dome along the end to be terminated. By providing a fullerene half-dome along an open end of the carbon nanotube, the end of the formed fastening element 12 becomes substantially inert, i.e., non-bonding to other atoms or molecules.

A second end 24 of the fastening element which is open, i.e., non-terminated, is bonded to a substrate 26 which may be in the form of various materials including metals, carbon (graphite or diamond), silicon, germanium, polymers and composites of the foregoing, to name a few. Other materials, provided they are capable of attaining a molten state, can also be employed.

Since the open end 24 of the nanotube is highly reactive and thus has a natural affinity for bonding to the desired substrate, the fastening element readily attaches to the substrate in a manner whereby the element stands up along the attachment surface. Nanotubes may be assisted in their alignment perpendicular to the surface by applying a strong electric field in that direction. This so-called affinity to migrate toward the surface is at least partially due to the low surface tension of the nanotube material. As will be understood by those skilled in the art, the tendency for the fastening elements to stand up promulgates mating between corresponding fastening elements.

Carbon nanotubes having ordered pairs of pentagons and heptagons may occur spontaneously to a limited extent during synthesis, thus forming hook shaped nanotubes as reported in MRS Bulletin, Vol. 19, No. 11, pp 43 - 49 (1994). However, in order to design carbon nanotubes such that they can be used effectively in micro-fastening systems, atomically dispersed catalysts may be necessary. For example, transition metals such as Fe and, more preferably, Ni, Co and Y have been shown to promote formation of single wall nanotubes or spiral structures as reported in Science 265, 635 (1994).

Curvature of the ends or other portions of relatively straight carbon nanotubes can be also accomplished by employing a template in proximity to a growing nanotube. In this regard, both on energetic and entropic grounds, a horizontally growing nanotube, when approaching a vertically positioned nanotube used as a template, has a higher probability to form ordered pairs of C_5 and C_7 carbon rings, i.e., pentagons and heptagons which

would cause the former to "wrap around" the latter. As such, specifically functionalized carbon nanotubes 14 useful as fastening elements 12 such as those illustrated in Figs. 4(a-b) can also be prepared without employing catalysts.

As shown in Figs. 1(a-c), only a moderate force F_c is required to selectively deform the nanotube and thereby accomplish an interconnection between the first and second fastening elements 12 and 12'. A much larger force F_o is required to break the interconnection between the fastening elements 12 and 12' of components in contact as demonstrated in Figs. 1(d-f). The hatched area in Fig. 2 represents the work required to close and re-open the gap and indicates the efficiency of a particular pair of mating nanoscale fastening elements.

As noted, while the fastening elements 12 and 12' can be formed into a number of different configurations, certain configurations are considered to be preferred. For a generic mechanical micro-fastening system, the opening and closing mechanism is shown in Figs. 1(a-f). Generic fastening elements, shown in these figures, contain a substantially triangular shaped head 30. Under this schematic embodiment the angled surfaces 32 and 32' slide past the other as the fastening elements come into contact as they advance toward an interlocked position. This angular orientation of approximately 45° along surfaces 32 and 32' allows for a minimal amount of lateral deflection of the fastening elements during the attachment step. The attachment surfaces 34 and 34' preferably slope downwardly and away from their respective stems 36 and 36' to form an interconnection requiring a relatively high separation force, i.e., $|F_o| >> |F_c|$.

Figs. 3(a-d) show one particular embodiment of the micro-fastening system, consisting of hook 16 and loop 18 fastening elements. Under this embodiment, as the hook and loop elements are advanced toward each other, the first end 22 of the hook deflects until there is sufficient clearance to insert into the aperture 40 of the loop element. As with the embodiment illustrated in Figs. 1(a-f), the hook and loop fastening system requires a

relatively high separation force $|F_o| >> |F_c|$ to detach the fastening elements as compared to the attachment forces.

Still other embodiments such as hook 16 to hook 16' fastening as illustrated with reference to Fig. 4a and spiral 20 to hook 16 fastening as illustrated in Fig. 4b are considered as practical applications. In essence, the shape of the resulting fastening elements is a function of the processing parameters, as such various fastening element configurations are contemplated.

Additionally, it should be understood that micro-fastening elements having different shapes can be formed upon the same substrate. Thus, alternating rows of specifically shaped fastening elements along a useful substrate is an effective application. Of course, microfastening elements of differing configurations can be randomly applied to a substrate, if desired.

While it will be apparent that the preferred embodiments of the invention disclosed are well calculated to fulfill the objects stated, it will be appreciated that the invention is susceptible to modification, variation and change without departing from the spirit thereof.

CLAIMS

1. A microfastening system comprising:

a first fastening element including a plurality of extending nanotubes; and

a second fastening element including a plurality of extending nanotubes;

whereby upon joining said first and second fastening elements, the extending nanotubes from each element become mechanically interconnected.

2. The microfastening system of Claim 1 wherein said at least one of first and second fastening elements further comprise a substrate from which said nanotubes extend.

3. The microfastening system of Claim 2 wherein said substrate is formed from materials selected from the group consisting of metals, carbon, silicon, germanium, polymers and composites thereof.

4. The microfastening system of Claim 1 wherein said nanotubes are at least partially multi-walled.

5. The microfastening system of Claim 1 wherein the nanotubes are functionalized to a non-linear shape.

6. The microfastening system of Claim 5 wherein the non-linear nanotubes of said fastening element are selected from hooks, loops, spirals and combinations thereof.

7. The microfastening system of Claim 1 wherein said nanotubes of at least one of said fastening elements are selectively deformable.

8. The microfastening system of Claim 1 wherein said fastening elements are reusable.

9. A microfastener comprising:

a substrate including an attachment surface; and

a plurality of functionalized non-linear nanotubes attached to and extending from said attachment surface.

10. The microfastener of Claim 9 wherein said substrate is formed from materials selected from the group consisting of metals, carbon, silicon, germanium, polymers and composites thereof.

11. The microfastener of Claim 9 wherein said nanotubes are at least partially multi-walled.

12. The microfastener of Claim 9 wherein the non-linear nanotubes of said fastening element are selected from hooks, loops, spirals and combinations thereof.

13. The microfastener of Claim 9 wherein at least some of the nanotubes of said microfastener are selectively deformable.

14. A method of manufacturing a microfastener comprising the steps of:

a) providing a substrate having an attachment surface;

b) introducing a plurality of open ended nanotubes to said substrate whereby said nanotubes are attracted to said attachment surface and become affixed thereto.

15. The method of Claim 14 wherein said nanotubes are functionalized prior to attaching to said substrate.

16. The method of Claim 14 wherein said nanotubes are functionalized during attachment to said substrate.

17. The method of Claim 14 wherein said nanotubes are functionalized after attachment to said substrate.

18. The method of Claim 14 wherein said substrate is formed from materials selected from the group consisting of metals, carbon, silicon, germanium, polymers and composites thereof.

19. The method of Claim 14 wherein said nanotubes are at least partially multi-walled.

20. The method of Claim 14 wherein the non-linear nanotubes of said fastening element are selected from hooks, loops, spirals and combinations thereof.

21. The method of Claim 14 wherein at least some of said nanotubes are selectively deformable.

22. The method of Claim 14 wherein said nanotubes are attached to said substrate in the presence of an electric field.

23. The method of Claim 14 wherein said microfastener is reusable.

ABSTRACT OF THE DISCLOSURE

The present invention relates to a micro-fastening system and, more particularly, to a mechanical micro-fastening system employing a plurality of mating nanoscale fastening elements and a method of manufacturing a micro-fastening system in accordance with the teachings of the present invention. The mating nanoscale fastening elements are formed by functionalizing nanotubes having an ordered array of hexagons with pentagons and heptagons at particular heterojunctions.

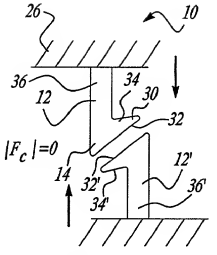

Fig-1a

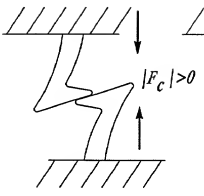

Fig-1b

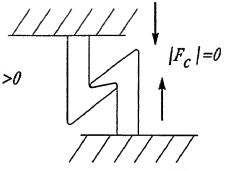

Fig-1c

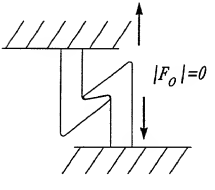

Fig-1d

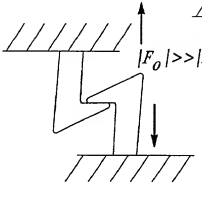

Fig-1e

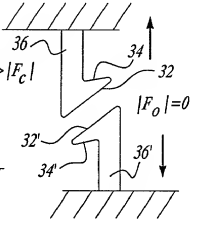

Fig-1f

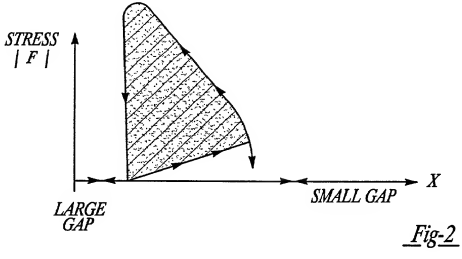

Fig-2

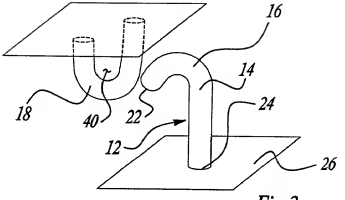

Fig-3a

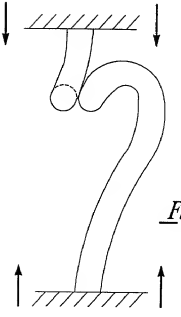

Fig-3b

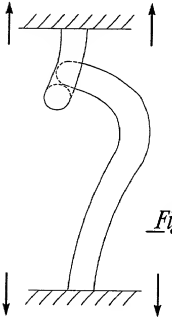

Fig-3c

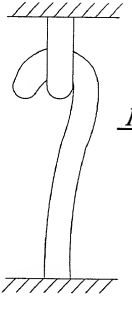

Fig-3d

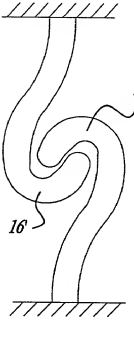

Fig-4a

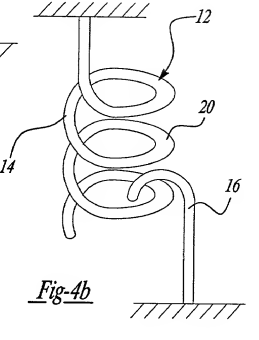

Fig-4b

DECLARATION AND POWER OF ATTORNEY

As a below named inventor, I hereby declare that:

My residence, post office address and citizenship are as stated below next to my name,

I believe I am the original, first and sole inventor (if only one name is listed below) or an original, first and joint inventor (if plural names are listed below) of the subject matter which is claimed and for which a patent is sought on the invention entitled

Micro-Fastening System and Method of Manufacture

the specification of which (check one)

[X] is attached hereto.

[ ] was filed on _____ as Application Serial No. _____ and was amended on _____ (if applicable).

I hereby state that I have reviewed and understand the contents of the above identified specification, including the claims, as amended by any amendment referred to above.

I acknowledge the duty to disclose information that is material to the patentability of the invention claimed in this application, or information that is material to the examination of this application, in accordance with Title 37, Code of Federal Regulations, section 1.56.

I hereby claim foreign priority benefits under Title 35, United States Code, section 119(a)-(d) of any foreign application(s) for patent or inventor's certificate listed below and have also identified below any foreign application for patent or inventor's certificate having a filing date before that of the application on which priority is claimed:

PRIOR FOREIGN APPLICATION(S)

			Priority Claim	
PCT/US99/02897	PCT	11 February 1999	X	
(Number)	(Country)	(Day/Month/Year filed)	Yes	No
(Number)	(Country)	(Day/Month/Year filed)	Yes	No
(Number)	(Country)	(Day/Month/Year filed)	Yes	No

DECLARATION AND POWER OF ATTORNEY

I hereby claim the benefit under Title 35, United States Code, §119(e) of any United States Provisional application(s) listed below:

PRIOR PROVISIONAL APPLICATIONS

60/074,463 (application serial number)	February 12, 1998 (Month / Day / Year filed)
_____ (application serial number)	_____ (Month / Day / Year filed)

I hereby claim the benefit under Title 35, United States Code, section 120 of any United States application(s) listed below and, insofar as the subject matter of each of the claims of this application is not disclosed in the prior United States application in the manner provided by the first paragraph of Title 35, United States Code, section 112, I acknowledge the duty to disclose material information as defined in Title 37, Code of Federal Regulations, section 1.56 which became available between the filing date of the prior application and the national or PCT international filing date of this application:

Application Serial No.	Filing Date	Status - patented, pending, abandoned

I hereby declare that all statements made herein of my own knowledge are true and that all statements made on information and belief are believed to be true; and further that these statements were made with the knowledge that willful false statements and the like so made are punishable by fine or imprisonment, or both, under Section 1001 of Title 18 of the United States Code and that such willful false statements may jeopardize the validity of the application or any patent issued thereon.

I hereby appoint Robert M. Siminski, Reg. No. 36,007, and each principal, attorney of counsel, associate and employee of Harness, Dickey & Pierce, P.L.C., who is a registered Patent Attorney, my attorney with full power of substitution and revocation, to prosecute this application and to transact all business in the Patent and Trademark Office connected therewith. I request the Patent and Trademark Office to direct all correspondence and telephone calls relative to this application to Harness, Dickey & Pierce, P.L.C., P. O. Box 828, Bloomfield Hills, Michigan 48303 (248) 641-1600.

Full name of sole or first inventor: David Tomanek

Inventor's signature: David Tomanek

Date: August 4, 2000

Residence: 1136 Poplar Lane, #4, East Lansing, Michigan 48823 MI

Citizenship: United States

Post Office Address: same as residence

20

Full name of second joint inventor, if any: Richard Enbody

Second Inventor's signature: [signature]

Date: August 15, 2000

Residence: 345 University Drive, East Lansing, Michigan 48823 MI

Citizenship: United States

Post Office Address: same as residence

Full name of third joint inventor, if any: Young-Kyun Kwon

Third Inventor's signature: _____

Date: _____

Residence: 1443D Spartan Village, East Lansing, Michigan 48823

Citizenship: South Korea

Post Office Address: same as residence

DECLARATION AND POWER OF ATTORNEY

As a below named inventor, I hereby declare that:

My residence, post office address and citizenship are as stated below next to my name,

I believe I am the original, first and sole inventor (if only one name is listed below) or an original, first and joint inventor (if plural names are listed below) of the subject matter which is claimed and for which a patent is sought on the invention entitled

Micro-Fastening System and Method of Manufacture

the specification of which (check one)

[X] is attached hereto.

[ ] was filed on _____ as Application Serial No. _____ and was amended on _____ (if applicable).

I hereby state that I have reviewed and understand the contents of the above identified specification, including the claims, as amended by any amendment referred to above.

I acknowledge the duty to disclose information that is material to the patentability of the invention claimed in this application, or information that is material to the examination of this application, in accordance with Title 37, Code of Federal Regulations, section 1.56.

I hereby claim foreign priority benefits under Title 35, United States Code, section 119(a)-(d) of any foreign application(s) for patent or inventor's certificate listed below and have also identified below any foreign application for patent or inventor's certificate having a filing date before that of the application on which priority is claimed:

PRIOR FOREIGN APPLICATION(S)

			Priority Claim	
PCT/US99/02897 (Number)	PCT (Country)	11 February 1999 (Day/Month/Year filed)	X Yes	No
(Number)	(Country)	(Day/Month/Year filed)	Yes	No
(Number)	(Country)	(Day/Month/Year filed)	Yes	No

DECLARATION AND POWER OF ATTORNEY

I hereby claim the benefit under Title 35, United States Code, §119(e) of any United States Provisional application(s) listed below:

PRIOR PROVISIONAL APPLICATIONS

60/074,463 (application serial number)	February 12, 1998 (Month / Day / Year filed)
_____ (application serial number)	_____ (Month / Day / Year filed)

I hereby claim the benefit under Title 35, United States Code, section 120 of any United States application(s) listed below and, insofar as the subject matter of each of the claims of this application is not disclosed in the prior United States application in the manner provided by the first paragraph of Title 35, United States Code, section 112, I acknowledge the duty to disclose material information as defined in Title 37, Code of Federal Regulations, section 1.56 which became available between the filing date of the prior application and the national or PCT international filing date of this application:

Application Serial No.	Filing Date	Status - patented, pending, abandoned
_____	_____	_____
_____	_____	_____
_____	_____	_____
_____	_____	_____

I hereby declare that all statements made herein of my own knowledge are true and that all statements made on information and belief are believed to be true; and further that these statements were made with the knowledge that willful false statements and the like so made are punishable by fine or imprisonment, or both, under Section 1001 of Title 18 of the United States Code and that such willful false statements may jeopardize the validity of the application or any patent issued thereon.

I hereby appoint Robert M. Siminski, Reg. No. 36,007, and each principal, attorney of counsel, associate and employee of Harness, Dickey & Pierce, P.L.C., who is a registered Patent Attorney, my attorney with full power of substitution and revocation, to prosecute this application and to transact all business in the Patent and Trademark Office connected therewith. I request the Patent and Trademark Office to direct all correspondence and telephone calls relative to this application to Harness, Dickey & Pierce, P.L.C., P. O. Box 828, Bloomfield Hills, Michigan 48303 (248) 641-1600.

Full name of sole or first inventor: David Tomanek

Inventor's signature: _____

Date: _____

Residence: 1136 Poplar Lane, #4, East Lansing, Michigan 48823

Citizenship: United States

Post Office Address: same as residence

DECLARATION AND POWER OF ATTORNEY

Full name of second joint inventor, if any: Richard Enbody

Second Inventor's signature: _____

Date: _____

Residence: 345 University Drive, East Lansing, Michigan 48823

Citizenship: United States

Post Office Address: same as residence

3rd

Full name of third joint Inventor, if any: Young-Kyun Kwon

Third Inventor's signature: Young-Kyun Kwon

Date: 8/22/00

Residence: 10944 San Pablo Ave. #324, El Cerrito, CA 94530 CA ~~1443D Spartan Village, East Lansing, Michigan 48823~~

Citizenship: South Korea

Post Office Address: same as residence